Amendments to the Specification

1. Title of the Invention

Please replace the title of the invention with the following:

3D Prestack Time Migration Method

2. Amendments to the Background of the Invention

a. Please amend the second full paragraph on page 1 as follows:

> Furthermore, conventional true amplitude weight terms are complicated and ~~to~~ do not consider many necessary factors. In a smoothly varying velocity field, for example, the amplitude weight depends on the travel-time, amplitude, ray-tube spreading factor, and takeoff angles in the shot and receiver points.

b. Please amend the second full paragraph on page 2 as follows:

> Thus, there is a long felt need for a relative true amplitude migration process which preserves relative amplitude, considers the appropriate factors, is accurate for long-offset data, and is suitable for vertically transversely isoropic (VTI) media**, also called transverse isotropy with a vertical symmetry axis**. The present invention addresses the above mentioned concerns.

3. Amendments to the Summary of the Invention.

Please replace the entire Summary of the Invention on page 3 with the following:

> One aspect of the invention is a method for migrating seismic data. A method according to this aspect of the invention includes selecting an image point, and generating a model of seismic velocity with respect to time. The model includes substantially horizontal layers each having a selected velocity and a selected thickness. A two-way travel time of seismic energy is determined from at least one seismic energy source position to at least one seismic receiver position wherein the seismic energy is reflected from the image point. A ray path is estimated from the at least one seismic source position to the image point and from the image point to the at least one seismic receiver position. The ray path is based on the source position, the receiver position and the velocity model. The two-way travel time of seismic energy through formations to the image point is then determined.

4. Amendments to the Detailed Description of Example Embodiments of the Present Invention

a. Please amend the first full paragraph on page 6 as indicated:

In one example embodiment of the present invention, a method of Kirchhoff migration is presented that includes ray-bending and ~~**relative true amplitude**~~ **amplitude preservation** in transversely isotropic **media** with a vertical symmetry axis (VTI media). The new method is called **3D prestack time migration**~~**"relative true amplitude migration" (TAPSTM)**~~. In one embodiment, the method uses a Kirchhoff operator and determines the kinematics or the shape of the operator from travel-times computed assuming *V(z)* and VTI media. In a further embodiment, to include ray bending, the earth is assumed to consist of horizontal layers so that the velocity profile used to calculate the travel times is simply a function of depth or time. Because ray-bending and VTI are considered, the takeoff angles for shots and receivers are calculated accurately compared to those obtained assuming straight rays. Thus, in further embodiments, the amplitude correction terms of the operator are determined using the takeoff angles for preserving the ~~**relative true**~~ amplitude. The method is robust in the presence of an irregular geometry and therefore lends itself well to application on most modern seismic marine, OBS, and land geometries.

b. Please amend the second paragraph on page 6 as indicated:

In a further embodiment, the method has the following main steps: 1. A time table is constructed to calculate the output imaging time. 2. The input is duplicated in the time domain for anti-alias filtering and resample. 3. The velocity, VTI parameter and mute tables are set up for each CDP and distributed uniformly among the processors. 4. The migration starts. The first processor reads a trace (record) and broadcasts the trace (record) to all processors. Then, all processors begin imaging the data. 5. The migration operators are built by calculating the high order (ray-bending effect) and VTI travel-times and amplitude correction terms. 6. ~~**TAPSTM**~~ **The 3D prestack time migration** completes the migration and outputs data in gather or non-gather modes.

c. Please amend the first full paragraph on page 7 as indicated:

In a further embodiment, the method further comprises determining a ray bending effect for large offset to depth rations. Those of ordinary skill will recognize that **dense** three-dimensional seismic reflection data is acquired on an increasingly routine basis. These large volumes of data offer the potential for very high-resolution 3D images of subsurface geology and subsequent estimation of the earth's physical properties (Lumley and Beydoun, 1992). In seismic acquisition, energy from all sources is spread from one scatter-point to all receivers. Consequently, all input traces can contain energy from the scattering point. When the input traces have a finite recording time, the scattered energy is restricted to traces within the prestack migration aperture of the scattering point. The objective of prestack migration is to gather this energy and sum it back to the

scatter-point location. The key points are how to obtain ~~a~~ **an** accurate travel-time for having better imaging and preserving the ~~**relative true amplitude**~~ **amplitudes**.

d. Please replace equation (12) on page 10 with the following equation:

$$T = T_g + T_s = \left(1 + \frac{1}{2} CC \frac{c_4 x_r^6}{T_{g0}^2}\right) + T_{s0}\left(1 + \frac{1}{2} CC \frac{c_4 x_r^6}{T_{s0}^2}\right) \tag{12}$$

e. Please amend the first full paragraph on page 11 as indicated:

In still a further embodiment of the present invention, a Kirchhoff time migration for transversely isotropic media with a vertical symmetry axis (VTI media) is provided using an offset-midpoint travel-time equation. The derivation of such an equation for VTI media requires approximations that pertain to high frequency and weak anisotropy. However, the resultant offset-midpoint travel-time equation for VTI media is highly accurate for even strong anisotropy. In one embodiment, the travel-time equation is dependent on two parameters: migration velocity and the anisotropy parameter **η** ~~**(eta).**~~

f. Please amend the last full paragraph starting on page 13 as indicated:

Knowledge of elastic ~~**parameter**~~ **parameters** (compressional and shear velocities and density) contrasts within the earth can be correlated to lithology and fluid changes. Elastic parameter contrasts manifest themselves on seismic records as a function of angle-dependent reflectivity. Interpretation of angle-dependent reflectivity, or amplitude variation with offset (AVO), on unmigrated records is often hindered by the geometrical spreading loss, as well as other factors. Various conventional migration algorithms involving weighted diffraction stacks proposed by geophysicists are based on Born[2] or Kirchhoff[3] approximations. In a further embodiment of the present invention, the principal issue in the attempt to recover angle-dependent reflection coefficients becomes the removal of the geometrical spreading factor of the primary reflections. In one embodiment, the weight function that achieves this aim is independent of the unknown reflector and correctly accounts for the recovery of the source pulse in the migrated image irrespective of the source-receiver configurations employed and the caustics occurring in the wave-field. Thus, one principal aim of the ~~**relative true-amplitude**~~ **amplitude-preserving** migration consists of removal of the geometrical spreading factor from seismic primary reflections without any knowledge of the search for subsurface reflector. In a further embodiment, the weight formula derived by Schleicher et al.[4] is expressed as,

g. Please amend the last full paragraph starting on page 15 as indicated:

Figure 2 illustrates the parameters that appear in equation ~~(17)~~ **(18)**. ~~T_r~~ ***T*** is equal to $T_s + T_g$ ~~**the imaging time**~~, T_s is the travel-time from source point *S* to the reflector *R*, and T_g is the travel-time from *R* to the receiver point *G*. V_r is the RMS velocity at the ***R*** **location**. **α is an azimuthal angle. The second term in equation (18) will have a contribution only if geologic dips are non-zero. Equation (18) is only valid for zero-dip conditions.** In still a further embodiment, equation (18) is derived based on the straight ray assumption. It might generate a large error in the weighting function calculation from a large offset *H*. As we know, the takeoff and emergence angles, α_s and α_g, depend not only on the geometry, but also on the velocity model. Thus, in one embodiment, angles α_s and α_g should not be computed **with the straight ray assumption** as following,

h. Please amend the second full paragraph on page 16 as indicated:

Equation ~~(17)~~**(18)** is derived using the straight ray assumption, hence in some embodiments, the weighting function is in error. However, in alternate embodiments, if we compute the travel-times using equation (16) which accounts for ray-bending and optionally VTI, the calculation of the takeoff and emergency angles, α_s and α_g using equation (19) **and the weights calculated with equation (18)** should yield a small error compared to the error obtained using equation (18) **and the straight ray assumption for takeoff and emergence angles, α_s and α_g.**

i. Please amend the section heading before the last paragraph on page 16 as indicated:

Pre-stack Kirchhoff time migration with ~~relative true~~ amplitude ***preservation*** *and weak VTI media*

j. Please replace equation (20) on page 17 to read as indicated:

$$I(T, x_i, y_i) = \int W(\xi, R) D(T = T_s + T_g) dxdy \qquad (20)$$

k. Please amend the first full paragraph on page 17, beginning immediately after equation (20) as indicated:

Where ~~$I(T_r, x_i, y_i)$~~ $I(T, x_i, y_i)$ is the image. ~~T_r~~ ***T*** is the ~~**image**~~ **travel** time **from shot point *S* to the receiver *G* going through the image point *R* or "imaging**

time." $W(\xi, R)$ is a weighting function, $D(T = T_s + T_g)$ is the time derivative of the input data~~. T is the total travel time from shot point S to the receiver G going through the image point R~~. In a further embodiment, by substituting equations (16), (17) and (19) into (20), we have a formula for the Kirchhoff time migration with ~~relative true~~ **preserved** amplitude and weak VTI media.

l. Please replace equation (21) on page 17 to read as follows:

$$T = T_s + T_g = \sqrt{T_0^2 + \frac{OS^2}{V_{rms}^2} + c_3 OS^4 \left(1 + \frac{1}{2} CC \frac{c_4 OS^6}{T_{s0}^2}\right)} + \sqrt{T_0^2 + \frac{OG^2}{V_{rms}^2} + c_3 OG^4 \left(1 + \frac{1}{2} CC \frac{c_4 OG^4}{T_{g0}^2}\right)} + \Delta T(VTI) \qquad (21)$$

m. Please amend the last paragraph starting on page 17 as indicated:

Equation (20) is the kernel part of some embodiments of the time migration for VTI media with ~~relative true~~ amplitude **preservation** including the ray-bending effect due to V(Z). In one example embodiment, FORTRAN is used to do the intensive computation, sample mapping from input to all of output targets, because FORTRAN is more efficient than C. The kernel part, FORTRAN codes, takes over 85% of the total time consuming. C codes handle the I/O, parameter controls.

n. Please amend the first full paragraph starting at the top of page 19 as indicated:

A one dimensional model was used for testing and comparisons between the conventional **straight ray** PSTM and this ~~TAPSTM~~ **ray bending PSTM**. Figure 3 shows the migration result by using conventional **straight ray** migration techniques. The gather output at the same CDP location is not flat. Figure 4 is the result of one example embodiment of the present invention. We see that the event at a CDP location is flat, which is what we expect.

o. Please amend the third full paragraph on page 19 as indicated:

In order to test the amplitude preserving, we have generated two datasets by using the same model, the first one is without the spreading factor, the second one is with the spreading factor. We use an example embodiment, to migrate the second model data and output its imaging gather at the different CDP locations. The amplitudes of the example embodiment of the method for different offsets should be equivalent to that of the CDP gather after NMO to the first dataset. Figure 7 shows the amplitudes at the different offsets. In Figure 7 the top is the

example embodiment, the middle is the NMO gather, and the bottom is a conventional **straight ray** migration technique.

p. Please amend the fourth full paragraph on page 19 as indicated:

Figure 8 is a 2D model displaying the density. In this example embodiment, ray-tracing has been used to generate the synthetic data using **compressional and shear** velocities and densities. Figure 9 and 10 are the gather outputs of a conventional migration technique and an example embodiment of the present invention. The example embodiment of the present invention does a better job than the conventional **straight ray** technique in dip structure.

q. Please amend the second full paragraph on page 20 as indicated:

In a further embodiment, correcting amplitude further comprises ~~**restoring essentially relative true**~~ **preserving** amplitude. In still a further embodiment, ~~**restoring relative true**~~ **preserving** amplitude further comprises recovering angle dependent ~~**reflection coefficients**~~ **amplitudes**.

r. Please replace the second equation on page 20 to read as follows:

$$W(\xi,R)=\frac{\sqrt{\cos\alpha_s\cos\alpha_g}}{v_s}\left\{T\left[\frac{T_g}{T_s^2}+\frac{T_s}{T_g^2}\right]+\frac{4L^2H^2\sin^2\alpha}{T_sT_gT^2V_r^4}\right\}$$

s. Please amend lines 3 –14 of page 21 as indicated

~~In a further embodiment, determining a travel time further comprises determining an offset midpoint travel time. In a further embodiment, determining an offset midpoint travel time further comprises applying essentially the following formula:~~

$$\cancel{T_s=\sqrt{T_0^2+\frac{x^2}{V_{rms}^2}-\frac{2\eta x^4}{V_{rms}^2[T_0^2V_{rms}^2+(1+2\eta)x^2]}}};$$

~~wherein~~

$$\cancel{\eta=\frac{\varepsilon-\delta}{1+2\delta}};$$

~~where ε and δ are the anisotropic parameters.~~

In a further embodiment, determining an offset midpoint traveltime further comprises applying essentially the following formula:

$$T = \sqrt{T_0^2 + \frac{x_s^2}{V_{rms}^2} - C(VTI)x_s^4} + \sqrt{T_0^2 + \frac{x_r^2}{V_{rms}^2} - C(VTI)x_s^4}$$

wherein

$$C(VTI) = \frac{2\eta}{V_{rms}^2[T_0^2 V_{rms}^2 + (1+2\eta)x^2]}$$

and

$$\eta = \frac{\varepsilon - \delta}{1 + 2\delta}$$

where ε and δ are the isotropic parameters.

t. Please amend the seventh full paragraph on page 22 as indicated:

In a further embodiment, the correcting amplitude further comprises ~~**restoring relative true**~~ **preserving** amplitude.

u. Please amend the first two full paragraphs on page 24 as indicated:

In a further embodiment, the means for correcting amplitude further comprises means for ~~**restoring essentially relative true**~~ **preserving** amplitude. In alternate embodiments, means for ~~**restoring essentially relative true**~~ **preserving the** amplitude comprise a computer, a workstation, any software running on any computer, or any other means that will occur to those of ordinary skill in the art.

In a further embodiment, the means for ~~**restoring relative true**~~ **preserving** amplitude further comprises means for recovering incidence angle dependent ~~**reflection coefficients**~~ **amplitudes**. In alternate embodiments, means for recovering angle dependent ~~**reflection coefficients**~~ **amplitudes** comprise a computer, a workstation, any software running on any computer, or any other means that will occur to those of ordinary skill in the art.

v. Please amend the last full paragraph on page 27 as indicated:

In a further embodiment, the means for correcting amplitude further comprises means for ~~**restoring true**~~ **preserving** amplitude. In alternate embodiments, means for ~~**restoring true**~~ **preserving** amplitude comprise a computer, a workstation, any software running on any computer, or any other means that will occur to those of ordinary skill in the art.

5. Amendments to the Abstract:

Please replace the entire Abstract on page 38 of the Specification with the following replacement Abstract:

A method is disclosed for migrating seismic data. The method includes selecting an image point and generating an initial model of seismic velocity with respect to time. The initial model includes substantially horizontal layers each having a selected interval velocity and a selected thickness. A travel time of seismic energy is determined from at least one seismic energy source position to at least one seismic receiver position, wherein the seismic energy is reflected from the image point. A ray path is estimated from the at least one seismic source position to the image point and from the image point to the at least one seismic receiver position. The ray path is based on the source position, the receiver position and the velocity model at the image location. A two-way travel time of seismic energy through formations to the image point is then determined.

5. Amendments to the Drawings:

Please amend Figure 7 as shown on the Marked-up Drawing in the attached Appendix A. Note that a Replacement Sheet for Figure 7 is also included in Appendix A.